Designation: D 3039/D 3039M – 95a

Standard Test Method for
Tensile Properties of Polymer Matrix Composite Materials[1]

This standard is issued under the fixed designation D 3039/D 3039M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method determines the in-plane tensile properties of polymer matrix composite materials reinforced by high-modulus fibers. The composite material forms are limited to continuous-fiber or discontinuous-fiber reinforced composites in which the laminate is balanced and symmetric with respect to the test direction.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

2. Referenced Documents

2.1 *ASTM Standards:*
D 792 Test Methods for Specific Gravity (Relative Density) and Density of Plastics by Displacement[2]
D 883 Terminology Relating to Plastics[2]
D 2584 Test Method for Ignition Loss of Cured Reinforced Resins[3]
D 2734 Test Methods for Void Content of Reinforced Plastics[3]
D 3171 Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion[4]
D 3878 Terminology of High-Modulus Reinforcing Fibers and Their Composites[4]
D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials[4]
E 4 Practices for Force Verification of Testing Machines[5]
E 6 Terminology Relating to Methods of Mechanical Testing[5]

E 83 Practice for Verification and Classification of Extensometers[5]
E 111 Test Method for Young's Modulus, Tangent Modulus, and Chord Modulus[5]
E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[6]
E 132 Test Method for Poisson's Ratio at Room Temperature[5]
E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[6]
E 251 Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages[5]
E 456 Terminology Relating to Quality and Statistics[6]
E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading[5]
E 1237 Guide for Installing Bonded Resistance Strain Gages[5]

3. Terminology

3.1 *Definitions*—Terminology D 3878 defines terms relating to high-modulus fibers and their composites. Terminology D 883 defines terms relating to plastics. Terminology E 6 defines terms relating to mechanical testing. Terminology E 456 and Practice E 177 define terms relating to statistics. In the event of a conflict between terms, Terminology D 3878 shall have precedence over the other standards.

3.2 *Descriptions of Terms Specific to This Standard:*

NOTE 1—If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets: [M] for mass, [L] for length, [T] for time, [θ] for thermodynamic temperature, and [nd] for non-dimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

3.2.1 *nominal value, n*—a value, existing in name only, assigned to a measurable property for the purpose of convenient designation. Tolerances may be applied to a nominal value to define an acceptable range for the property.

3.2.2 *transition region, n*—a strain region of a stress-strain or strain-strain curve over which a significant change in the

slope of the curve occurs within a small strain range.

3.2.3 *transition strain,* $\epsilon^{transition}$ *[nd],* n—the strain value at the mid-range of the transition region between the two essentially linear portions of a bilinear stress-strain or strain-strain curve.

3.2.3.1 *Discussion*—Many filamentary composite materials show essentially bilinear behavior during loading, such as seen in plots of either longitudinal stress versus longitudinal strain or transverse strain versus longitudinal strain. There are varying physical reasons for the existence of a transition region. Common examples include: matrix cracking under tensile loading and ply delamination.

3.3 *Symbols:*

3.3.1 *A*—minimum cross-sectional area of a coupon.

3.3.2 B_y—percent bending for a uniaxial coupon of rectangular cross-section about y-axis of the specimen (about the narrow direction).

3.3.3 B_z—percent bending for a uniaxial coupon of rectangular cross-section about the z-axis of the specimen (about the wide direction).

3.3.4 *CV*—coefficient of variation statistic of a sample population for a given property (in percent).

3.3.5 *E*—modulus of elasticity in the test direction.

3.3.6 F^{tu}—ultimate tensile strength in the test direction.

3.3.7 F^{su}—ultimate shear strength in the test direction.

3.3.8 *h*—coupon thickness.

3.3.9 L_g—extensometer gage length.

3.3.10 L_{min}—minimum required bonded tab length.

3.3.11 *n*—number of coupons per sample population.

3.3.12 *P*—load carried by test coupon.

3.3.13 P^f—load carried by test coupon at failure.

3.3.14 P^{max}—maximum load carried by test coupon prior to failure.

3.3.15 s_{n-1}—standard deviation statistic of a sample population for a given property.

3.3.16 *w*—coupon width.

3.3.17 x_i—test result for an individual coupon from the sample population for a given property.

3.3.18 $\bar{x}$—mean or average (estimate of mean) of a sample population for a given property.

3.3.19 δ—extensional displacement.

3.3.20 ϵ—general symbol for strain, whether normal strain or shear strain.

3.3.21 e—indicated normal strain from strain transducer or extensometer.

3.3.22 σ—normal stress.

3.3.23 v—Poisson's ratio.

4. Summary of Test Method

4.1 A thin flat strip of material having a constant rectangular cross-section is mounted in the grips of a mechanical testing machine and monotonically loaded in tension while recording load. The ultimate strength of the material can be determined from the maximum load carried prior to failure. If the coupon strain is monitored with strain or displacement transducers then the stress-strain response of the material can be determined, from which the ultimate tensile strain, tensile modulus of elasticity, Poisson's ratio, and transition strain can be derived.

5. Significance and Use

5.1 This test method is designed to produce tensile property data for material specifications, research and development, quality assurance, and structural design and analysis. Factors that influence the tensile response and should therefore be reported include the following: material methods of material preparation and lay-up, specimen stacking sequence, specimen preparation, specimen conditioning, environment of testing, specimen alignment and gripping, speed of testing, time at temperature, void content and volume percent reinforcement. Properties, in the test direction, which may be obtained from this test method include the following:

5.1.1 Ultimate tensile strength,

5.1.2 Ultimate tensile strain,

5.1.3 Tensile chord modulus of elasticity,

5.1.4 Poisson's ratio, and

5.1.5 Transition strain.

6. Interferences

6.1 *Material and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, and damage induced by improper coupon machining are known causes of high material data scatter in composites.

6.2 *Gripping*—A high percentage of grip-induced failures especially when combined with high material data scatter, is an indicator of specimen gripping problems. Specimen gripping methods are discussed further in 7.2.4, 8.2, and 11.5.

6.3 *System Alignment*—Excessive bending will cause premature failure, as well as highly inaccurate modulus of elasticity determination. Every effort should be made to eliminate excess bending from the test system. Bending may occur due to misaligned grips, or from specimens themselves if improperly installed in the grips or out-of-tolerance due to poor specimen preparation. If there is any doubt as to the alignment inherent in a given test machine then the alignment should be checked as discussed in 7.2.5.

7. Apparatus

7.1 *Micrometers*—A micrometer with a 4- to 5-mm [0.16- to 0.20-in] nominal diameter double-ball interface shall be used to measure the thickness of the specimen. A micrometer with a flat anvil interface shall be used to measure the width of the specimen. The accuracy of the instruments shall be suitable for reading to within 1 % of the sample width and thickness. For typical specimen geometries, an instrument with an accuracy of ± 2.5 µm [±0.0001 in.] is adequate for thickness measurement, while an instrument with an accuracy of ± 25 µm [±0.001 in.] is adequate for width measurement.

7.2 *Testing Machine*—The testing machine shall be in conformance with Practices E 4, and shall satisfy the following requirements:

7.2.1 *Testing Machine Heads*—The testing machine shall have both an essentially stationary head and a movable head.

7.2.2 *Drive Mechanism*—The testing machine drive mechanism shall be capable of imparting to the movable head a controlled velocity with respect to the stationary head. The velocity of the movable head shall be capable of being regulated as specified in 11.3.

7.2.3 *Load Indicator*—The testing machine load-sensing device shall be capable of indicating the total load being carried by the test specimen. This device shall be essentially free from inertia-lag at the specified rate of testing and shall indicate the load with an accuracy over the load range(s) of interest of within ± 1 % of the indicated value. The load range(s) of interest may be fairly low for modulus evaluation, much higher for strength evaluation, or both, as required.

NOTE 2—Obtaining precision load data over a large range of interest in the same test, such as when both elastic modulus and ultimate load are being determined, place extreme requirements on the load cell and its calibration. For some equipment a special calibration may be required. For some combinations of material and load cell, simultaneous precision measurement of both elastic modulus and ultimate strength may not be possible and measurement of modulus and strength may have to be performed in separate tests using a different load cell range for each test.

7.2.4 *Grips*—Each head of the testing machine shall carry one grip for holding the test specimen so that the direction of load applied to the specimen is coincident with the longitudinal axis of the specimen. The grips shall apply sufficient lateral pressure to prevent slippage between the grip face and the coupon. If tabs are used the grips should be long enough that they overhang the beveled portion of the tab by approximately 10–15 mm [0.5 in.]. It is highly desirable to use grips that are rotationally self-aligning to minimize bending stresses in the coupon.

NOTE 3—Grip surfaces that are lightly serrated, approximately 1 serration/mm [25 serrations/in.], have been found satisfactory for use in wedge-action grips when kept clean and sharp; coarse serrations may produce grip-induced failures in untabbed coupons. Smooth gripping surfaces have been used successfully with either hydraulic grips or an emery-cloth interface, or both.

7.2.5 *System Alignment*—Poor system alignment can be a major contributor to premature failure, to elastic property data scatter, or both. Practice E 1012 describes bending evaluation guidelines and describes potential sources of misalignment during tensile testing. In addition to Practice E 1012 the degree of bending in a tensile system can also be evaluated using the following related procedure. Specimen bending is considered separately in 11.6.1.

7.2.5.1 A rectangular alignment coupon, preferably similar in size and stiffness to the test specimen of interest, is instrumented with a minimum of three longitudinal strain gages of similar type, two on the front face across the width and one on the back face of the specimen, as shown in Fig. 1. Any difference in indicated strain between these gages during loading provides a measure of the amount of bending in the thickness plane (B_y) and width plane (B_z) of the coupon. The strain gage location should normally be located in the middle of the coupon gage section (if modulus determination is a concern), near a grip (if premature grip failures are a problem), or any combination of these areas.

7.2.5.2 When evaluating system alignment it is advisable to perform the alignment check with the same coupon inserted in each of the four possible installation permutations (described relative to the initial position): initial (top-front facing observer), rotated back-to-front only (top-back facing observer), rotated end-for-end only (bottom-front facing observer), and rotated both front-to-back and end-to-end (bottom-back facing observer). These four data sets provide an indication of whether the bending is due to the system
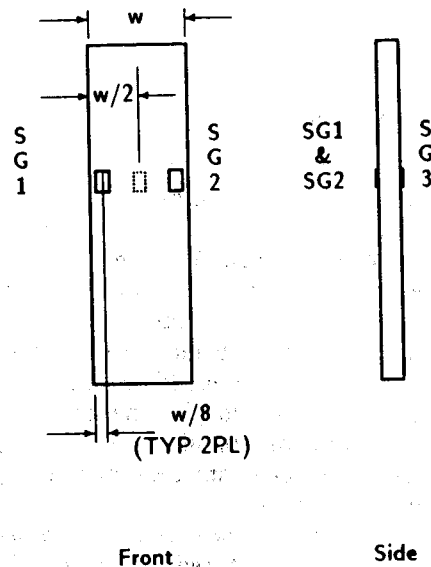

Front   Side

FIG. 1 Gage Locations for System Alignment Check Coupon

itself or to tolerance in the alignment check coupon or gaging.

7.2.5.3 The zero strain point may be taken either prior to gripping or after gripping. The strain response of the alignment coupon is subsequently monitored during the gripping process, the tensile loading process, or both. Eqs. 1–3 use these indicated strains to calculate the ratio of the percentage of bending strain to average extensional strain for each bending plane of the alignment coupon, and the total percent bending, B_{total}. Plotting percent bending versus axial average strain is useful in understanding trends in the bending behavior of the system.

7.2.5.4 Problems with failures during gripping would be reason to examine bending strains during the gripping process in the location near the grip. Concern over modulus data scatter would be reason to evaluate bending strains over the modulus evaluation load range for the typical transducer location. Excessive failures near the grips would be reason to evaluate bending strains near the grip at high loading levels. While the maximum advisable amount of system misalignment is material and location dependent, good testing practice is generally able to limit percent bending to a range of 3 to 5 % at moderate strain levels (>1000 $\mu\epsilon$). A system showing excessive bending for the given application should be readjusted or modified.

$$B_y = \frac{\varepsilon_{ave} - \varepsilon_3}{\varepsilon_{ave}} \times 100 \qquad (1)$$

$$B_z = \frac{4/3 \, (\varepsilon_2 - \varepsilon_1)}{\varepsilon_{ave}} \times 100 \qquad (2)$$

where:

B_y = percent bending about system y-axis (about the narrow plane), as calculated by Eq. 1, %,

B_z = percent bending about system z-axis (about the wide plane), as calculated by Eq. 2, %,

$\left.\begin{array}{l} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{array}\right\}$ = indicated longitudinal strains displayed by gages 1, 2, and 3, respectively, of Fig. 1, $\mu\epsilon$ and

$$\varepsilon_{ave} = \frac{(\varepsilon_1 + \varepsilon_2)/2 + \varepsilon_3}{2}.$$

The total bending component is:

$$B_{total} = |B_y| + |B_z| \qquad (3)$$

7.3 *Strain-Indicating Device*—Load-strain data, if required, shall be determined by means of either a strain transducer or an extensometer. Attachment of the strain-indicating device to the coupon shall not cause damage to the specimen surface. If Poisson's ratio is to be determined the specimen shall be instrumented to measure strain in both longitudinal and lateral directions. If the modulus of elasticity is to be determined the longitudinal strain should be simultaneously measured on opposite faces of the specimen to allow for a correction due to any bending of the specimen (see 11.6 for further guidance).

7.3.1 *Bonded Resistance Strain Gage Selection*—Strain gage selection is a compromise based on the type of material. An active gage length of 6 mm [0.25 in.] is recommended for most materials. Active gage lengths should not be less than 3 mm [0.125 in.].[7] Gage calibration certification shall comply with Test Methods E 251. When testing woven fabric laminates gage selection should consider the use of an active gage length that is at least as great as the characteristic repeating unit of the weave. Some guidelines on the use of strain gages on composites follow. A general reference on the subject is Tuttle and Brinson.[8]

7.3.1.1 Surface preparation of fiber-reinforced composites in accordance with Practice E 1237 can penetrate the matrix material and cause damage to the reinforcing fibers, resulting in improper coupon failures. Reinforcing fibers should not be exposed or damaged during the surface preparation process. The strain gage manufacturer should be consulted regarding surface preparation guidelines and recommended bonding agents for composites, pending the development of a set of standard practices for strain gage installation surface preparation of fiber-reinforced composite materials.

7.3.1.2 Consideration should be given to the selection of gages having larger resistances to reduce heating effects on low-conductivity materials. Resistances of 350Ω or higher are preferred. Additional consideration should be given to the use of the minimum possible gage excitation voltage consistent with the desired accuracy (1 to 2 volts is recommended) to further reduce the power consumed by the gage. Heating of the coupon by the gage may affect the performance of the material directly, or it may affect the indicated strain due to a difference between the gage temperature compensation factor and the coefficient of thermal expansion of the coupon material.

7.3.1.3 Consideration of some form of temperature compensation is recommended, even when testing at standard laboratory atmosphere. Temperature compensation is required when testing in non-ambient temperature environments.

7.3.1.4 Consideration should be given to the transverse sensitivity of the selected strain gage. The strain gage manufacturer should be consulted for recommendations on transverse sensitivity corrections and effects on composites. This is particularly important for a transversely mounted gage used to determine Poisson's ratio, as discussed in Note 12.

7.3.2 *Extensometers*—For most purposes the extensometer gage length should be in the range of 10–50 mm [0.5–2.0 in.]. Extensometers shall satisfy, at a minimum, Practice E 83, Class B-1 requirements for the strain range of interest, and shall be calibrated over that strain range in accordance with Practice E 83. For extremely stiff materials, or for measurement of transverse strains, the fixed error allowed by Class B-1 extensometers may be significant, in which case Class A extensometers should be considered. The extensometer shall be essentially free of inertia lag at the specified speed of testing, and the weight of the extensometer should not induce bending strains greater than those allowed in 6.3.

NOTE 4—It is generally less difficult to perform strain calibration on extensometers of longer gage length as less precision in displacement is required of the extensometer calibration device.

7.4 *Conditioning Chamber*—When conditioning materials at non-laboratory environments, a temperature-/vapor-level controlled environmental conditioning chamber is required that shall be capable of maintaining the required temperature to within ± 3°C [± 5°F] and the required relative vapor level to within ± 3 %. Chamber conditions shall be monitored either on an automated continuous basis or on a manual basis at regular intervals.

7.5 *Environmental Test Chamber*—An environmental test chamber is required for test environments other than ambient testing laboratory conditions. This chamber shall be capable of maintaining the gage section of the test specimen at the required test environment during the mechanical test.

8. Sampling and Test Specimens

8.1 *Sampling*—Test at least five specimens per test condition unless valid results can be gained through the use of fewer specimens, such as in the case of a designed experiment. For statistically significant data the procedures outlined in Practice E 122 should be consulted. Report the method of sampling.

NOTE 5—If specimens are to undergo environmental conditioning to equilibrium, and are of such type or geometry that the weight change of the material cannot be properly measured by weighing the specimen itself (such as a tabbed mechanical coupon), then use another traveler coupon of the same nominal thickness and appropriate size (but without tabs) to determine when equilibrium has been reached for the specimens being conditioned.

8.2 *Geometry*—Design of mechanical test coupons, especially those using end-tabs, remains to a large extent an art rather than a science, with no industry consensus on how to approach the engineering of the gripping interface. Each major composite testing laboratory has developed gripping methods for the specific material systems and environments commonly encountered within that laboratory. Comparison of these methods shows them to differ widely, making it

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[7] A typical gage would have a 0.25 in. active gage length, 350Ω resistance, a strain rating of 3 % or better, and the appropriate environmental resistance and thermal coefficient.

[8] Tuttle, M. E. and Brinson, H. F., "Resistance-Foil Strain-Gage Technology as Applied to Composite Materials," *Experimental Mechanics*, Vol 24, No. 1, March 1984; pp. 54–65; errata noted in Vol 26, No. 2, June 1986, pp. 153–154.

extremely difficult to recommend a universally useful approach or set of approaches. Because of this difficulty, definition of the geometry of the test coupon is broken down into the following three levels, which are discussed further in each appropriate section:

Purpose	Degree of Geometry Definition
8.2.1 *General Requirements*	Mandatory Shape & Tolerances
8.2.2 *Specific Recommendations*	Non-Mandatory Suggested Dimensions
8.2.3 *Detailed Examples*	Non-Mandatory Typical Practices

8.2.1 *General Requirements:*

8.2.1.1 *Shape, Dimensions, and Tolerances*—The complete list of requirements for specimen shape, dimensions, and tolerances is shown in Table 1.

8.2.1.2 *Use of Tabs*—Tabs are not required. The key factor in the selection of specimen tolerances and gripping methods is the successful introduction of load into the specimen and the prevention of premature failure due to a significant discontinuity. Therefore, determine the need to use tabs, and specification of the major tab design parameters, by the end result: acceptable failure mode and location. If acceptable failure modes occur with reasonable frequency then there is no reason to change a given gripping method (see 11.10).

8.2.2 *Specific Recommendations:*

8.2.2.1 *Width, Thickness, and Length*—Select the specimen width and thickness to promote failure in the gage section and to assure that the specimen contains a sufficient number of fibers in the cross-section to be statistically representative of the bulk material. The specimen length should normally be substantially longer than the minimum requirement in order to minimize bending stresses due to minor grip eccentricities, keep the gage section as far from the grips as reasonably possible, and provide a significant amount of material under stress and therefore produce a more statistically significant result. The minimum requirements for specimen design shown in Table 1 are by themselves insufficient to create a properly dimensioned and toleranced coupon drawing. Therefore, recommendations on other important dimensions are provided for typical material configurations in Table 2. These geometries have been found by a number of testing laboratories to produce acceptable failure modes on a wide variety of material systems, but use of them does not guarantee success for every existing or future material system.

8.2.2.2 *Gripping/Use of Tabs*—There are many material configurations, such as multi-directional laminates, fabric-based materials, or randomly reinforced sheet molding compounds, which can be successfully tested without tabs. However, tabs are strongly recommended when testing unidirectional materials (or strongly unidirectionally dominated laminates) to failure in the fiber direction. Tabs may also be required when testing unidirectional materials in the matrix direction to prevent gripping damage.

8.2.2.3 *Tab Geometry*—Recommendations on important dimensions are provided for typical material configurations in Table 2. These dimensions have been found by a number of testing laboratories to produce acceptable failure modes on a wide variety of material systems, but use of them does not guarantee success for every existing or future material system. The selection of a tab configuration that can successfully produce a gage section tensile failure is dependent upon the coupon material, coupon ply orientation, and the type of grips being used. When pressure-operated non-wedge grips are used with care, squared-off 90° tabs have been used successfully. Wedge-operated grips have been used most successfully with tabs having low bevel angles (7–10°) and a feathered smooth transition into the coupon. For alignment purposes it is essential that the tabs be of matched thickness.

8.2.2.4 *Friction Tabs*—Tabs need not always be bonded to the material under test to be effective in introducing the load into the specimen. Friction tabs, essentially non-bonded tabs held in place by the pressure of the grip, and often used with emery cloth or some other light abrasive between the tab and the coupon, have been successfully employed in some applications. In specific cases, lightly serrated wedge grips (see Note 3) have been successfully used with only emery cloth as the interface between the grip and the coupon. However, the abrasive used must be able to withstand significant compressive loads. Some types of emery cloth have been found ineffective in this application due to disintegration of the abrasive.[9]

8.2.2.5 *Tab Material*—The most consistently used bonded tab material has been continuous E-glass fiber-reinforced polymer matrix materials (woven or unwoven) in a [0/90]ns laminate configuration. The tab material is commonly applied at 45° to the loading direction to provide a soft interface. Other configurations that have reportedly been successfully used have incorporated steel tabs, or tabs made of the same material as is being tested.

8.2.2.6 *Bonded Tab Length*—When using bonded tabs, estimate the minimum suggested tab length for bonded tabs by the following simple equation. As this equation does not account for the peaking stresses that are known to exist at the ends of bonded joints, the tab length calculated by this equation should normally be increased by some factor to reduce the chances of joint failure:

$$L_{min} = F^{tu}h/2F^{su} \qquad (4)$$

where:

L_{min} = minimum required bonded tab length, mm [in.],

TABLE 1 Tensile Specimen Geometry Requirements

Parameter	Requirement
Coupon Requirements:	
shape	constant rectangular cross-section
minimum length	gripping + 2 times width + gage length
specimen width	as needed[A]
specimen width tolerance	±1 % of width
specimen thickness	as needed
specimen thickness tolerance	±4 % of thickness
specimen flatness	flat with light finger pressure
Tab Requirements (if used):	
tab material	as needed
fiber orientation (composite tabs)	as needed
tab thickness	as needed
tab thickness variation between tabs	±1 % tab thickness
tab bevel angle	5 to 90°, inclusive
tab step at bevel to specimen	feathered without damaging specimen

[A] See 8.2.2 or Table 2 for recommendations.

[9] E-Z Flex Metalite K224 cloth, Grit 120-J, available from Norton Company, Troy, New York 12181, has been found satisfactory in this application. Other equivalent types of emery cloth should also be suitable.

TABLE 2 Tensile Specimen Geometry Recommendations[A]

Fiber Orientation	Width, mm [in.]	Overall Length, mm [in.]	Thickness, mm [in.]	Tab Length, mm [in.]	Tab Thickness, mm [in.]	Tab Bevel Angle, °
0° unidirectional	15 [0.5]	250 [10.0]	1.0 [0.040]	56 [2.25]	1.5 [0.062]	7 or 90
90° unidirectional	25 [1.0]	175 [7.0]	2.0 [0.080]	25 [1.0]	1.5 [0.062]	90
balanced and symmetric	25 [1.0]	250 [10.0]	2.5 [0.100]	emery cloth	—	—
random-discontinuous	25 [1.0]	250 [10.0]	2.5 [0.100]	emery cloth	—	—

[A] Dimensions in this table and the tolerances of Figs. 2 or 3 are recommendations only and may be varied so long as the requirements of Table 1 are met.

F^{tu} = ultimate tensile strength of coupon material, MPa [psi],

h = coupon thickness, mm [in.], and

F^{su} = ultimate shear strength of adhesive, coupon material, or tab material (whichever is lowest), MPa [psi].

8.2.2.7 *Bonded Tab Adhesive*—Any high-elongation (tough) adhesive system that meets the environmental requirements may be used when bonding tabs to the material under test. A uniform bondline of minimum thickness is desirable to reduce undesirable stresses in the assembly.

8.2.3 *Detailed Examples*—The minimum requirements for specimen design discussed in 8.2.1 are by themselves

insufficient to create a properly dimensioned and toleranced coupon drawing. Dimensionally toleranced specimen drawings for both tabbed and untabbed forms are shown a examples in Fig. 2 (SI) and Fig. 3 (inch-pound). Th tolerances on these drawings are fixed, but satisfy th requirements of Table 1 for all of the recommended config urations of Table 2. For a specific configuration the toler ances on Figs. 2 and 3 might be able to be relaxed.

8.3 *Specimen Preparation:*

8.3.1 *Panel Fabrication*—Control of fiber alignment i critical. Improper fiber alignment will reduce the measure properties. Erratic fiber alignment will also increase th

DRAWING NOTES:
1. INTERPRET DRAWING IN ACCORDANCE WITH ANSI Y14.5M-1982, SUBJECT TO THE FOLLOWING:
2. ALL DIMENSIONS IN MILLIMETRES WITH DECIMAL TOLERANCES AS FOLLOWS:

NO DECIMAL	.X	.XX
± 3	± 1	± .3

3. ALL ANGLES HAVE TOLERANCE OF ± .5°.
4. PLY ORIENTATION DIRECTION TOLERANCE RELATIVE TO -A- WITHIN ± .5°.
5. FINISH ON MACHINED EDGES NOT TO EXCEED 1.6√ (SYMBOLOGY IN ACCORDANCE WITH ASA B46.1, WITH ROUGHNESS HEIGHT IN MICROMETRES.)
6. VALUES TO BE PROVIDED FOR THE FOLLOWING, SUBJECT TO ANY RANGES SHOWN ON THE FIELD OF DRAWING: MATERIAL, LAY-UP, PLY ORIENTATION REFERENCE RELATIVE TO -A-, OVERALL LENGTH, GAGE LENGTH, COUPON THICKNESS, TAB MATERIAL, TAB THICKNESS, TAB LENGTH, TAB BEVEL ANGLE, TAB ADHESIVE.
7. NO ADHESIVE BUILDUP ALLOWED IN THIS AREA.

COUPON WITH TABS

COUPON WITHOUT TABS
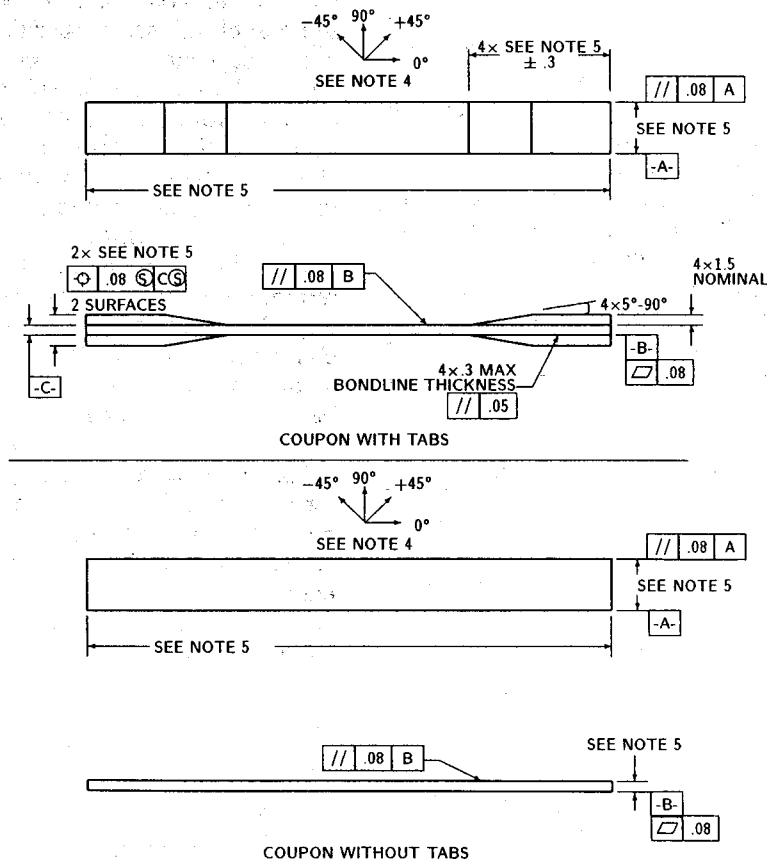
FIG. 2 Tension Test Specimen Drawing (SI)

DRAWING NOTES:
1. INTERPRET DRAWING IN ACCORDANCE WITH ANSI Y14.5M-1982, SUBJECT TO THE FOLLOWING:
2. ALL DIMENSIONS IN INCHES WITH DECIMAL TOLERANCES AS FOLLOWS:

.X	.XX	.XXX
±.1	±.03	±.01

3. ALL ANGLES HAVE TOLERANCE OF ±.5°.
4. PLY ORIENTATION DIRECTION TOLERANCE RELATIVE TO -A- WITHIN ±.5°.
5. FINISH ON MACHINED EDGES NOT TO EXCEED 64√ (SYMBOLOGY IN ACCORDANCE WITH ASA B46.1, WITH ROUGH-NESS HEIGHT IN MICROINCHES.)
5. VALUES TO BE PROVIDED FOR THE FOLLOWING, SUBJECT TO ANY RANGES SHOWN ON THE FIELD OF DRAWING: MATERIAL, LAY-UP, PLY ORIENTATION REFERENCE RELATIVE TO -A-, OVERALL LENGTH, GAGE LENGTH, COUPON THICKNESS, TAB MATERIAL, TAB THICKNESS, TAB LENGTH, TAB BEVEL ANGLE, TAB ADHESIVE.
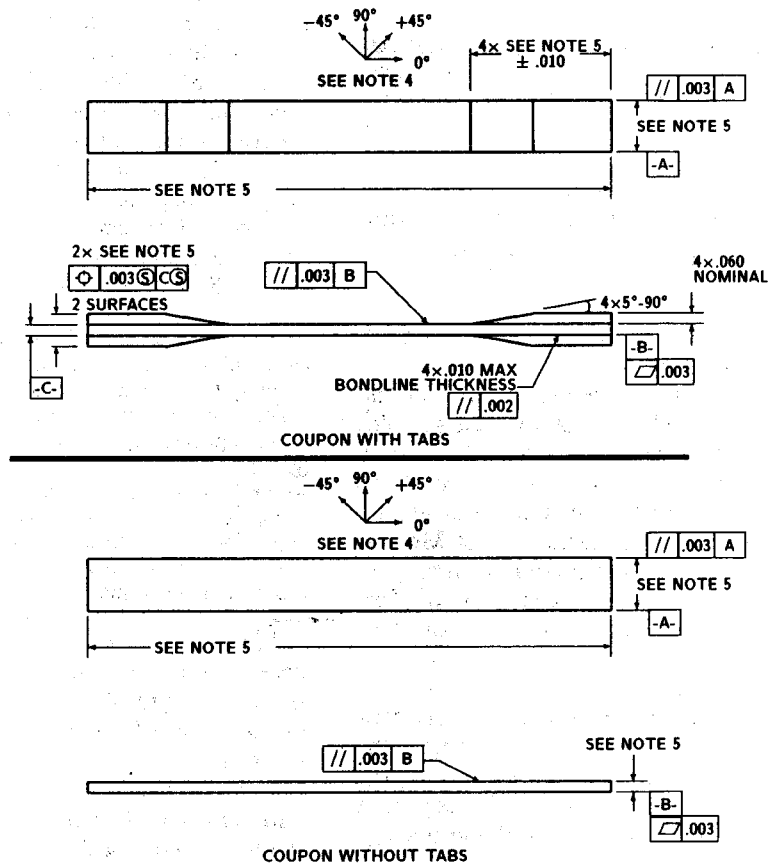6. NO ADHESIVE BUILDUP ALLOWED IN THIS AREA.

FIG. 3   Tension Test Specimen Drawing (inch-pound)

coefficient of variation. The specimen preparation method shall be reported.

8.3.2 *Machining Methods*—Specimen preparation is extremely important for this specimen. Mold the specimens individually to avoid edge and cutting effects or cut from them plates. If they are cut from plates, take precautions to avoid notches, undercuts, rough or uneven surfaces, or delaminations due to inappropriate machining methods. Obtain final dimensions by water lubricated precision sawing, milling, or grinding. The use of diamond tooling has been found to be extremely effective for many material systems. Edges should be flat and parallel within the specified tolerances.

8.3.3 *Labeling*—Label the coupons so that they will be distinct from each other and traceable back to the raw material, and in a manner that will both be unaffected by the test and not influence the test.

9. Calibration

9.1 The accuracy of all measuring equipment shall have certified calibrations that are current at the time of use of the equipment.

10. Conditioning

10.1 *Standard Conditioning Procedure*—Unless a different environment is specified as part of the experiment, condition the test specimens in accordance with Procedure C of Test Method D 5229/D 5229M and store and test at

TABLE 3   Specimen Alignment and Chord Modulus Calculation Strain Ranges

Tensile Chord Modulus Calculation Longitudinal Strain Range		Longitudinal Strain Checkpoint for Bending
Start Point $\mu\epsilon^A$	End Point $\mu\epsilon$	$\mu\epsilon$
1000[B]	3000	2000

[A] 1000 $\mu\epsilon$ = 0.001 absolute strain.
[B] This strain range is to be contained in the lower half of the stress/strain curve. For materials that fail below 6000 μe a strain range of 25–50 % of ultimate is recommended.

standard laboratory atmosphere (23 ± 3°C [73 ± 5°F] and 50 ± 10 % relative humidity).

11. Procedure

11.1 *Parameters To Be Specified Prior to Test:*

11.1.1 The tension specimen sampling method, coupon type and geometry, and conditioning travelers (if required).

11.1.2 The tensile properties and data reporting format desired.

NOTE 6—Determine specific material property, accuracy, and data reporting requirements prior to test for proper selection of instrumentation and data recording equipment. Estimate operating stress and strain levels to aid in transducer selection, calibration of equipment, and determination of equipment settings.

11.1.3 The environmental conditioning test parameters.

11.1.4 If performed, the sampling method, coupon geometry, and test parameters used to determine density and reinforcement volume.

11.2 *General Instructions:*

11.2.1 Report any deviations from this test method, whether intentional or inadvertent.

11.2.2 If specific gravity, density, reinforcement volume or void volume are to be reported then obtain these samples from the same panels being tension tested. Specific gravity and density may be evaluated by means of Test Methods D 792. Volume percent of the constituents may be evaluated by one of the matrix digestion procedures of Test Method D 3171, or, for certain reinforcement materials such as glass and ceramics, by the matrix burn-off technique of Test Method D 2584. The void content equations of Test Methods D 2734 are applicable to both Test Method D 2584 and the matrix digestion procedures.

11.2.3 Following final specimen machining and any conditioning, but before the tension testing, determine the specimen area as A = w × h, at three places in the gage section, and report the area as the average of these three determinations to the accuracy in 7.1. Record the average area in units of mm² (in.²).

11.3 *Speed of Testing*—Set the speed of testing to effect a nearly constant strain rate in the gage section. If strain control is not available on the testing machine, this may be approximated by repeated monitoring and adjusting of the rate of load application to maintain a nearly constant strain rate, as measured by strain transducer response versus time. The strain rate should be selected so as to produce failure within 1 to 10 minutes. If the ultimate strain of the material cannot be reasonably estimated, initial trials should be conducted using standard speeds until the ultimate strain of the material and the compliance of the system are known, and the strain rate can be adjusted. The suggested standard speeds are:

11.3.1 *Strain-Controlled Tests*—A standard strain rate of 0.01 min⁻¹.

11.3.2 *Constant Head-Speed Tests*—A standard head displacement rate of 2 mm/min [0.05 in./min].

NOTE 7—Use of a fixed head speed in testing machine systems with a high compliance may result in a strain rate that is much lower than required. Use of wedge grips can cause extreme compliance in the system, especially when using compliant tab materials. In some such cases actual strain rates 10 to 50 times lower than estimated by head speeds have been observed.

11.4 *Test Environment*—Condition the specimen to the desired moisture profile and, if possible, test under the same conditioning fluid exposure level. However, cases such as elevated temperature testing of a moist specimen place unrealistic requirements on the capabilities of common testing machine environmental chambers. In such cases the mechanical test environment may need to be modified, for example, by testing at elevated temperature with no fluid exposure control, but with a specified limit on time to failure from withdrawal from the conditioning chamber. Modifications to the test environment shall be recorded.

11.4.1 Store the specimen in the conditioned environment until test time, if the testing area environment is different than the conditioning environment.

11.5 *Specimen Insertion*—Place the specimen in the grips of the testing machine, taking care to align the long axis of the gripped specimen with the test direction. Tighten the grips, recording the pressure used on pressure controllable (hydraulic or pneumatic) grips.

NOTE 8—The ends of the grip-jaws on wedge-type grips should be even with each other following insertion to avoid inducing a bending moment that results in premature failure of the specimen at the grip. When using untabbed specimens, a folded strip of medium grade (80–150 grit) emery cloth between the specimen faces and the grip jaws (grit-side toward specimen) provides a non-slip grip on the specimen without jaw serration damage to the surface of the specimen. When using tabbed specimens, insert the coupon so that the grip jaws extend approximately 10–15 mm [0.5 in.] past the beginning of the tapered portion of the tab. Coupons having tabs that extend beyond the grips are prone to failure at the tab ends due to excessive interlaminar stresses.

11.6 *Transducer Installation*—If strain response is to be determined attach the strain-indication transducer(s) to the specimen, symmetrically about the mid-span, mid-width location. Attach the strain recording instrumentation to the transducers on the specimen.

11.6.1 When determining modulus of elasticity it is recommended that at least one specimen per like sample be evaluated with back-to-back axial transducers in order to evaluate the percent bending, using Eq. 5, at the average axial strain checkpoint value (the mid-range of the appropriate chord modulus strain range) shown in Table 3. A single transducer can be used if the percent bending is no more than 3 %. When bending is greater than 3 % averaged strains from back-to-back transducers of like kind are recommended.

$$B_y = \frac{|\varepsilon_f - \varepsilon_b|}{|\varepsilon_f + \varepsilon_b|} \tag{5}$$

where:

ε_f = indicated strain from front transducer, $\mu\varepsilon$,

ε_b = indicated strain from back transducer, $\mu\varepsilon$, and

B_y = percent bending in specimen.

11.7 *Loading*—Apply the load to the specimen at the specified rate until failure, while recording data.

11.8 *Data Recording*—Record load versus strain (or transducer displacement) continuously, or at frequent regular intervals. If a transition region or initial ply failures are noted, record the load, strain, and mode of damage at such points. If the specimen is to be failed, record the maximum load, the failure load, and the strain (or transducer displacement) at, or as near as possible to, the moment of rupture.

NOTE 9—Other valuable data that can be useful in understanding testing anomalies and gripping or specimen slipping problems includes load versus head displacement data and load versus time data.

11.9 *Failure Mode*—Record the mode and location of failure of the specimen. Choose, if possible, a standard description using the three-part failure mode code that is shown in Fig. 4.

11.10 *Grip/Tab Failures*—Re-examine the means of load introduction into the material if a significant fraction of failures in a sample population occur within one specimen width of the tab or grip. Factors considered should include the tab alignment, tab material, tab angle, tab adhesive, grip type, grip pressure, and grip alignment.

12. Calculation

12.1 *Tensile Stress/Tensile Strength*—Calculate the ultimate tensile strength using Eq. 6 and report the results to three significant figures. If the tensile modulus is to be calculated, determine the tensile stress at each required data point using Eq. 7.

$$F^{tu} = P^{max}/A \tag{6}$$

$$\sigma_i = P_i/A \tag{7}$$

where:

F^{tu} = ultimate tensile strength, MPa [psi],
P_{max} = maximum load prior to failure, N [lbf],
σ_i = tensile stress at i-th data point, MPa [psi],
P_i = load at i-th data point, N [lbf], and
A = average cross-sectional area from 11.2.3, mm² [in.²].

12.2 *Tensile Strain/Ultimate Tensile Strain*—If tensile modulus or ultimate tensile strain is to be calculated, and material response is being determined by an extensometer, determine the tensile strain from the indicated displacement at each required data point using Eq. 8 and report the results to three significant figures.

$$\epsilon_i = \delta_i/L_g \tag{8}$$

where:

ϵ_i = tensile strain at i-th data point, µε,
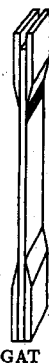δ_i = extensometer displacement at i-th data point, mm [in.], and
L_g = extensometer gage length, mm [in.].
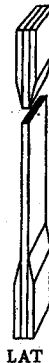
12.3 *Tensile Modulus of Elasticity:*

NOTE 10—To minimize potential effects of bending it is recommended that the strain data used for modulus of elasticity determination be the average of the indicated strains from each side of the specimen, as discussed in 7.3 and 11.6.

LIT   GAT   LAT   DGM

LGM   SGM   AGM(1)   AGM(2)   XGM

First Character		Second Character		Third Character	
Failure Type	Code	Failure Area	Code	Failure Location	Code
Angled	A	Inside grip/tab	I	Bottom	B
edge Delamination	D	At grip/tab	A	Top	T
Grip/tab	G	<1W from grip/tab	W	Left	L
Lateral	L	Gage	G	Right	R
Multi-mode	M(xyz)	Multiple areas	M	Middle	M
long. Splitting	S	Various	V	Various	V
eXplosive	X	Unknown	U	Unknown	U
Other	O				

FIG. 4 Tensile Test Failure Codes/Typical Modes

12.3.1 *Tensile Chord Modulus of Elasticity*—Select the appropriate chord modulus strain range from Table 3. Calculate the tensile chord modulus of elasticity from the stress-strain data using Eq. 9. If data is not available at the exact strain range end points (as often occurs with digital data), use the closest available data point. Report the tensile chord modulus of elasticity to three significant figures. Also report the strain range used in the calculation. A graphical example of chord modulus is shown in Fig. 5.

12.3.1.1 The tabulated strain ranges should only be used for materials that do not exhibit a transition region (a significant change in the slope of the stress-strain curve) within the given strain range. If a transition region occurs within the recommended strain range, then a more suitable strain range shall be used and reported.

$$E^{chord} = \Delta\sigma/\Delta\varepsilon \qquad (9)$$

where:

E^{chord} = tensile chord modulus of elasticity, GPa [psi],

$\Delta\sigma$ = difference in applied tensile stress between the two strain points of Table 3, MPa [psi], and

$\Delta\varepsilon$ = difference between the two strain points of Table 3 (nominally 0.002).

12.3.2 *Tensile Modulus of Elasticity (Other Definitions)*— Other definitions of elastic modulus may be evaluated and reported at the user's discretion. If such data is generated and reported, report also the definition used, the strain range used, and the results to three significant figures. Test Method E 111 provides additional guidance in the determination of Modulus of Elasticity.

NOTE 11—An example of another modulus definition is the secondary chord modulus of elasticity for materials that exhibit essentially bilinear stress-strain behavior. An example of secondary chord modulus is shown in Fig. 5.

12.4 *Poisson's Ratio:*

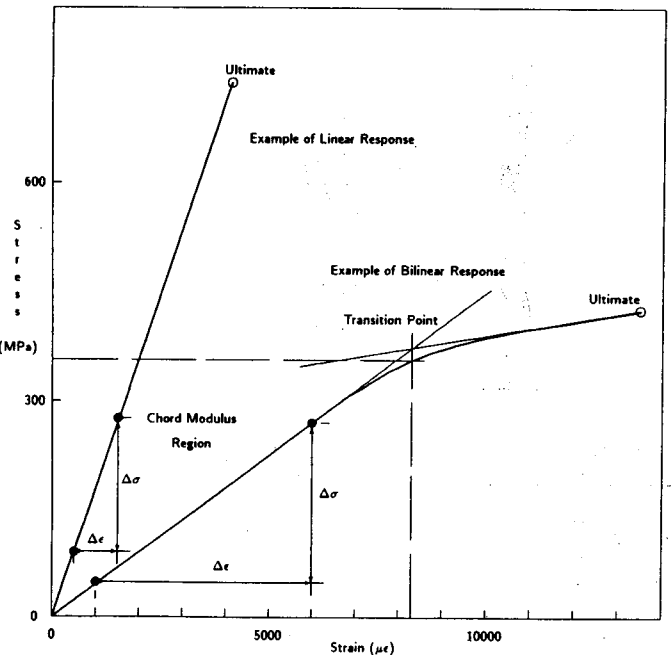NOTE 12—If bonded resistance strain gages are being used, the error produced by the transverse sensitivity effect on the transverse gage will generally be much larger for composites than for metals. An accurate measurement of Poisson's ratio requires correction for this effect. The strain gage manufacturer should be contacted for information on the use of correction factors for transverse sensitivity.

12.4.1 *Poisson's Ratio By Chord Method*—Select the appropriate chord modulus longitudinal strain range from Table 3. Determine (by plotting or otherwise) the transverse strain (measured perpendicular to the applied load), ε_t, at each of the two longitudinal strains (measured parallel to the applied load), ε_l, strain range end points. If data is not available at the exact strain range end points (as often occurs with digital data), use the closest available data point. Calculate Poisson's ratio by Eq. 10 and report to three significant figures. Also report the strain range used.

$$\nu = -\Delta\varepsilon_t/\Delta\varepsilon_l \qquad (10)$$

where:

ν = Poisson's ratio

$\Delta\varepsilon_t$ = difference in lateral strain between the two longitudinal strain points of Table 3, $\mu\varepsilon$, and

$\Delta\varepsilon_l$ = difference between the two longitudinal strain points of Table 3 (nominally either 0.001, 0.002, or 0.005).

12.4.2 *Tensile Poisson's Ratio (Other Definitions)*—Other definitions of Poisson's ratio may be evaluated and reported at the user's direction. If such data is generated and reported, report also the definition used, the strain range used, and the results to three significant figures. Test Method E 132 provides additional guidance in the determination of Poisson's ratio.

12.5 *Transition Strain*—Where applicable, determine the transition strain from either the bilinear longitudinal stress versus longitudinal strain curve or the bilinear transverse strain versus longitudinal strain curve. Create a best linear fit or chord line for each of the two linear regions and extend the lines until they intersect. Determine to three significant digits the longitudinal strain that corresponds to the intersection point and record this value as the transition strain. Report also the method of linear fit (if used) and the strain ranges over which the linear fit or chord lines were determined. A graphical example of transition strain is shown in Fig. 5.

12.6 *Statistics*—For each series of tests calculate the average value, standard deviation, and coefficient of variation (in percent) for each property determined:

$$\bar{x} = \left(\sum_{i=1}^{n} x_i\right)/n \qquad (11)$$

$$s_{n-1} = \sqrt{\left(\sum_{i=1}^{n} x_i^2 - n\bar{x}^2\right)/(n-1)} \qquad (12)$$

$$CV = 100 \times s_{n-1}/\bar{x} \qquad (13)$$

where:

$\bar{x}$ = sample mean (average),
s_{n-1} = sample standard deviation,
CV = sample coefficient of variation, in percent,
n = number of specimens, and
x_i = measured or derived property.

13. Report

13.1 Report the following information, or references

FIG. 5 Typical Tensile Stress-Strain Curves

pointing to other documentation containing this information, to the maximum extent applicable (reporting of items beyond the control of a given testing laboratory, such as might occur with material details or panel fabrication parameters, shall be the responsibility of the requestor):

13.1.1 The revision level or date of issue of this test method.

13.1.2 The date(s) and location(s) of the test.

13.1.3 The name(s) of the test operator(s).

13.1.4 Any variations to this test method, anomalies noticed during testing, or equipment problems occurring during testing.

13.1.5 Identification of the material tested including: material specification, material type, material designation, manufacturer, manufacturer's lot or batch number, source (if not from manufacturer), date of certification, expiration of certification, filament diameter, tow or yarn filament count and twist, sizing, form or weave, fiber areal weight, matrix type, prepreg matrix content, and prepreg volatiles content.

13.1.6 Description of the fabrication steps used to prepare the laminate including: fabrication start date, fabrication end date, process specification, cure cycle, consolidation method, and a description of the equipment used.

13.1.7 Ply orientation stacking sequence of the laminate.

13.1.8 If requested, report density, volume percent reinforcement, and void content test methods, specimen sampling method and geometries, test parameters, and test results.

13.1.9 Average ply thickness of the material.

13.1.10 Results of any non-destructive evaluation tests.

13.1.11 Method of preparing the test specimen, including specimen labeling scheme and method, specimen geometry, sampling method, coupon cutting method, identification of tab geometry, tab material, and tab adhesive used.

13.1.12 Calibration dates and methods for all measurement and test equipment.

13.1.13 Type of test machine, grips, jaws, grip pressure, alignment results, and data acquisition sampling rate and equipment type.

13.1.14 Results of system alignment evaluations, if any such were done.

13.1.15 Dimensions of each test specimen.

13.1.16 Conditioning parameters and results, use of travelers and traveler geometry, and the procedure used if other than that specified in the test method.

13.1.17 Relative humidity and temperature of the testing laboratory.

13.1.18 Environment of the test machine environmental chamber (if used) and soak time at environment.

13.1.19 Number of specimens tested.

13.1.20 Speed of testing.

13.1.21 Transducer placement on the specimen and transducer type for each transducer used.

13.1.22 If strain gages were used, the type, resistance, size, gage factor, temperature compensation method, transverse sensitivity, lead-wire resistance, and any correction factors employed.

13.1.23 Stress-strain curves and tabulated data of stress versus strain for each specimen.

13.1.24 Percent bending results for each specimen so evaluated.

13.1.25 Individual strengths and average value, standard deviation, and coefficient of variation (in percent) for the population. Note if the failure load was less than the maximum load prior to failure.

13.1.26 Individual strains at failure and the average value, standard deviation, and coefficient of variation (in percent) for the population.

13.1.27 Strain range used for chord modulus and Poisson's ratio determination.

13.1.28 If another definition of modulus of elasticity is used in addition to chord modulus, describe the method used, the resulting correlation coefficient (if applicable), and the strain range used for the evaluation.

13.1.29 Individual values of modulus of elasticity, and the average value, standard deviation, and coefficient of variation (in percent) for the population.

13.1.30 If another definition of Poisson's ratio is used in addition to the chordwise definition, describe the method used, the resulting correlation coefficient (if applicable), and the strain range used for the evaluation.

13.1.31 Individual values of Poisson's ratio, and the average value, standard deviation, and coefficient of variation (in percent) for the population.

13.1.32 If transition strain is determined, the method of linear fit (if used) and the strain ranges over which the linear fit or chord lines were determined.

13.1.33 Individual values of transition strain (if applicable), and the average value, standard deviation, and coefficient of variation (in percent) for the population.

13.1.34 Failure mode and location of failure for each specimen.

14. Precision and Bias

14.1 *Precision*—The data required for the development of a precision statement is not available for this test method. Committee D-30 is currently planning a round-robin test series for this test method in order to determine precision.

14.2 *Bias*—Bias cannot be determined for this test method as no acceptable reference standard exists.

15. Keywords

15.1 composite materials; modulus of elasticity; Poisson's ratio; tensile properties; tensile strength